

## **Stack Gas Flow Rate**

**SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT**

**METHOD 2.1**

**DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW  
RATE (S-TYPE PITOT TUBE)**

**TECHNICAL SUPPORT SERVICES  
APPLIED SCIENCE AND TECHNOLOGY  
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## **METHOD 2.1**

### **DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (S-TYPE PITOT TUBE)**

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## **METHOD 2.1**

### **DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (S-TYPE PITOT TUBE)**

#### **Section 1 of 3**

#### **1. Overview**

##### **1.1 Principle**

The average gas velocity in a stack is determined from the gas density and from measurement of the average velocity head with an S-type (Stausscheibe or reverse type) Pitot tube.

##### **1.2 Applicability**

This method measures the average velocity of a gas stream from which gas flow is quantified.

This procedure does not apply at measurement sites which fail to meet the criteria of Method 1.1, Section 1.2. Section 2.4 of Method 1.1 shows how to determine cyclonic or swirling flow conditions. When unacceptable conditions exist, use alternative procedures or see Chapter X for non-standard conditions. Examples of acceptable

alternative procedures are (1) installing straightening vanes, (2) calculating the total volumetric flow rate stoichiometrically, or (3) moving to a measurement site with acceptable flow conditions.

If time-weighted volumetric flow rate is required, perform reference point velocity monitoring as described in Chapter X for non-standard conditions.

## **METHOD 2.1**

### **DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (S-TYPE PITOT TUBE)**

#### **Section 2 of 3**

## **2. Field Procedures**

### **2.1 Apparatus**

#### **2.1.1 Pitot Tube**

Specifications are described below. Any other apparatus that has been demonstrated capable of meeting these specification will be considered acceptable, subject to approval of the Executive Officer.

##### **a. S-Type Pitot tube**

The S-type Pitot tube (Figure 2.1-1) shall be made of metal tubing (e.g. stainless steel). The external tubing diameter (dimension  $D_t$ , Figure 2.1-2b) should be

between 0.48 and 0.95 cm (3/16 to 3/8 in.). There must be an equal distance from the base of each leg of the Pitot tube to its face-opening plane (dimensions  $P_A$  and  $P_B$ , Figure 2.1-2b). This distance should be between 1.05 and 1.50 times the external tubing diameter. The face openings of the Pitot tube should be aligned as shown in Figure 2.1-1; however, slight misalignments of the openings are permissible (see Figure 2.1-3).

The S-type Pitot tube must have a known coefficient. Assign an identification number to the Pitot tube and permanently mark or engrave it on the body of the tube.

Before its initial use, carefully examine the S-type Pitot tube in top, side, and end views to verify that the face openings of the tube are aligned within the specifications illustrated in Figure 2.1-2 or 2.1-3. Do not use

the Pitot tube if it fails to meet specification. Before each use carefully reexamine the tube in top, side and end views. If the Pitot face openings are still aligned within the specifications illustrated in Figure 2.1-1 or 2.1-3, assume that the baseline coefficient of the Pitot tube has not changed. If, however, the tube has been damaged to the extent that it no longer meets the specifications of Figure 2.1-2 or 2.1-3, repair the damage to restore proper alignment of the face openings or recalibrate or discard the tube (refer to Chapter III).

b. Standard Pitot Tube

A standard Pitot tube may be used instead of an S-type, provided it meets the specifications stated in this method.

Note, however, that the static and impact pressure hole of standard Pitot tubes are susceptible to



plugging in high moisture-laden and particulate-laden gas streams.

Whenever a standard Pitot tube is used to perform a traverse, adequate proof must be furnished that the openings of the Pitot tube have not plugged up during the traverse period. To do so, take a velocity head ( $\Delta P$ ) reading at the final traverse point, cleaning out the impact and static holes of the standard Pitot tube by "back-purging" with pressurized air and then take another  $\Delta P$  reading. If the  $\Delta P$  readings made before and after the air purge are the same ( $\pm 5\%$ ), the traverse is acceptable. Otherwise, reject the run. Note that if  $\Delta P$  at the final traverse point is unsuitably low, another point may be selected. If "back-purging" at regular intervals is part of the procedure, take comparative  $\Delta P$  readings, as above, for the last two back purges at which suitable high  $\Delta P$  readings are observed.

The standard Pitot tube should, have a known coefficient, obtained either (1) directly from the National Bureau of Standards, Route 270, Quince Orchard Road, Gaithersbury, Maryland, or (2) by calibration against another standard Pitot tube with an NBS-traceable coefficient. A standard Pitot tube designed according to the specifications given below and illustrated in Figure 2.1-4 may be used. Pitot tubes designed according to these specifications will have baseline coefficients of about  $0.99 \pm 0.01$ .

1. Hemispherical (shown in Figure 2.1-4), ellipsoidal, or conical tip.
2. A minimum of six diameters straight run (based on D, the external diameter of the tube) between the tip and the static pressure holes.

3. A minimum of eight diameters straight run between the static pressure holes and the centerline of the external tube, following the 90-degree bend.
4. Static pressure holes of equal size (approximately 0.1 D), equally spaced in a piezometer ring configuration.
5. Ninety degree bend, with curved or mitered junction.

If the standard Pitot tube is used as part of an assembly, the tube shall be in an interference-free arrangement and subject to the approval of the Executive Officer.

c. S-Type Pitot Assemblies

During sample and velocity traverses, the S-type Pitot tube is not always used alone. In many instances, the Pitot tube is used

in combination with other source sampling components (thermocouple, sampling probe, nozzle) as part of an "assembly". The presence of other sampling components can sometimes affect the baseline value of the S-type Pitot tube coefficient. Therefore, an assigned, or known, baseline coefficient value may not be valid for a given assembly.

The baseline and assembly coefficient values will be identical only when the relative placement of the interference effects are eliminated (see Figures 2.1-6 through 2.1-8). Calibrate according to the procedure outlines in Chapter III, Calibrations.

Do not use any S-type Pitot tube assembly which is constructed so that the impact pressure opening plane of the Pitot tube is below the entry plane of the nozzle (see Figure 2.1-6b).

After each field use, check the face opening alignment of the Pitot tube and remeasure the intercomponent spacing of the assembly. If the intercomponent spacings have not changed and the face opening alignment is acceptable, assume that the coefficient of the assembly has not changed.

If the face opening alignment is not within the specifications of Figure 2.1-2 or 2.1-3, either repair the damage or replace the Pitot tube and calibrate the new assembly, if necessary.

If the intercomponent spacings have changed, restore the original spacings or recalibrate the assembly.

#### 2.1.2 Differential Pressure Gauge

Use an inclined manometer, or an equivalent device such as a magnehelic

gauge. Most commercial sampling trains are equipped with a 10 in. water column inclined-vertical manometer, having 0.01 in.  $H_2O$  divisions on the 1 to 10 in. vertical scale.

This type of manometer, or other gauge of equivalent sensitivity such as a magnehelic gauge, is satisfactory for the measurement of  $\Delta P$  values as low as 1.3 mm (0.05 in.)  $H_2O$ . However, a differential pressure gauge of greater sensitivity must be used if one of the following criteria exists:

1. The arithmetic average of all  $\Delta P$  readings at the traverse points in the stacks is less than 1.3 mm (0.05 in.)  $H_2O$ .
2. For a traverse of 12 or more points, more than 10 percent of the individual  $\Delta P$  readings are below 1.3 mm (0.05 in.)  $H_2O$ .

3. For a traverse of fewer than 12 points, more than one  $\Delta P$  reading is below 1.3 mm (0.05 in.)  $H_2O$ .

As an alternative to these criteria, the following calculation may be performed to determine the necessity of using a more sensitive differential pressure gauge:

$$T = \frac{\sum_{i=1}^n (\Delta P_i + K)^{1/2}}{\sum_{i=1}^n (\Delta P_i)^{1/2}}$$

where:

$T$  = Factor, dimensionless

$\Delta P_i$  = Individual velocity head reading  
at a traverse point, mm or in.  
 $H_2O$

$n$  = Total number of traverse points

$K$  = 0.13 mm  $H_2O$  when metric units are  
used and 0.005 in.  $H_2O$  when  
English units are used

If  $T$  is greater than 1.05, the velocity head data are unacceptable and a more sensitive differential pressure gauge must be used.

#### 2.1.3 Temperature Gauge

Use thermocouple, liquid-filled bulb thermometer, bimetallic thermometer, mercury-in-glass thermometer, or other gauge capable of measuring temperature to within 1.5 percent of the minimum absolute stack temperature.

Attach the temperature gauge to the Pitot tube so that the sensor tip does not touch metal and the gauge does not interfere with the Pitot tube face openings (see Figure 2.1-1 and Figure 2.1-7).

#### 2.1.4 Pressure Probe and Gauge

A piezometer tube and mercury or water-filled U-tube manometer capable of measuring stack pressure to within 2.5 mm (0.1 in.) Hg is used. The static tap



of a standard type Pitot tube or one leg of an S-type Pitot tube with the face opening planes positioned parallel to the gas flow, may also be used as the pressure probe.

#### 2.1.5 Barometer

A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm (0.1 in.) Hg may be used.

Alternatively, the barometric reading may be obtained from a National Weather Service station. Request the station value (which is the absolute barometric pressure) and adjust for elevation difference between the NWS station and the sampling point at the rate of minus 2.5 mm (0.1 in.) Hg per 30 m (100 ft) elevation increase, or plus the same adjustment for elevation decrease.

#### 2.1.6 Gas Density Determination Equipment

Use Method 3.1 equipment to determine the stack gas dry molecular weight, if needed, and Method 4.1 or Method 5.1 equipment for moisture content.

### 2.2 Procedure

#### 2.2.1 Equipment Setup and Leak Check

Set up the apparatus as shown in Figure 2.1-1. Capillary tubing or a surge tank may be installed between the manometer and Pitot tube to dampen  $\Delta P$  fluctuations. Conduct a pretest leak check as follows: (1) Blow through the Pitot impact opening until at least 80 percent of full scale or 7.6 cm (3 in.)  $H_2O$  pressure, whichever is less, registers on the manometer. Close the impact opening. The pressure should remain stable for at least 15 seconds. (2) Do the same for the static pressure side, but use suction to obtain the minimum of 7.6 cm (3 in.)  $H_2O$ . Other

leak check procedures may be used, subject to the approval of the Executive Officer.

#### 2.2.2 Manometer Level and Zero

Because the manometer level and zero may drift due to vibrations and temperature changes, make periodic checks during the traverse.

Record all necessary data as shown on the example, or use a similar data sheet (see Figure 2.1-5). When using a differential pressure gauge (e.g. magnehelic gauge), make sure it is firmly mounted and adjust the pointer to zero.

#### 2.2.3 Velocity Head and Temperature

Measure the velocity head and temperature at the traverse points specified by Method 1.1. Use the proper differential pressure gauge for the range of  $\Delta P$  values encountered. Change to a more sensitive gauge if needed and

remeasure the  $\Delta P$  and temperature readings at each traverse point. To validate the traverse run, it is mandatory to conduct a post test leak check as described in Section 2.2.1.

#### 2.2.4 Static Pressure

Measure the static pressure in the stack. One reading is usually adequate.

#### 2.2.5 Atmospheric Pressure

Determine the atmospheric pressure. Correct for stack height if the pressure is measured at ground level and the sample is point more than 100 ft above ground level.

#### 2.2.6 Stack Gas Molecular Weight

Determine the stack gas molecular weight. For combustion processes, or processes that emit essentially  $\text{CO}_2$ ,  $\text{O}_2$ ,  $\text{CO}$ , and  $\text{N}_2$ , use Method 3.1. For processes emitting essentially air, an analysis need not be conducted; use a

dry molecular weight of 29.0. Other methods may be used for other processes, subject to the approval of the Executive Officer.

#### 2.2.7 Stack Gas Moisture Content

Obtain moisture content from Reference Method 4.1 or Method 5.1.

#### 2.2.8 Stack Cross Sectional Area

Determine the cross sectional area of the stack or duct at the sampling location by measuring the stack dimensions.

### 2.3 Calibration

Refer to Chapter III.

## METHOD 2.1

### DETERMINATION OF STACK GAS VELOCITY AND VOLUMETRIC FLOW RATE (S-TYPE PITOT TUBE)

#### Section 3 of 3

### 3. Engineering Calculations and Reporting

Perform calculations, recording values to at least one decimal place more than that of the acquired data.

Round off final results. A calculation sheet is shown in Figure 2.1-9.

#### 3.1 Nomenclature

A = Stack cross sectional area,  $\text{ft}^2$

$B_w$  = Moisture content in gas stream,  
percent (from Method 4.1 or Method  
5.1)

$C_p$  = Pitot tube coefficient, dimensionless

$P_{\text{bar}}$  = Barometric pressure at measurement  
site, in. Hg

$P_{\text{static}}$  = Stack static pressure, in. Hg

$P_s$  = Absolute stack gas pressure  
( $P_{\text{bar}} + P_{\text{static}}$ )

$P_{\text{std}}$  = Standard absolute pressure, 29.92 in.  
Hg

$F_p$  = Pressure correction factor,  
dimensionless

$$F_p = \frac{P_{\text{std}}}{P_{\text{bar}} + P_{\text{static}}} \sqrt{\frac{29.92}{P_s}}$$

$t_s$  = Stack gas temperature, °F

$T_{\text{std}}$  = Standard absolute temperature, 520°R

$M_d$  = Wet molecular weight of stack gas,  
lb/lb-mole (from Method 3.1)

$M_{\text{std}}$  = Standard dry molecular weight, 28.95  
lb/lb-mole

$F_d$  = Gas density correction factor,  
dimensionless

$$F_d = \sqrt{\frac{M_{std}}{M_d}} \sqrt{\frac{28.95}{M_d}}$$

$H$  = Velocity head of stack gas, in.  $H_2O$

$V_t$  = Average velocity of stack gas during  
test, ft/sec

### 3.2 Volumetric Flow Rate

a. Stack gas velocity at each traverse point,  
ft/sec:

$$V = 2.90 \sqrt{H \cdot (t_s + 460)}$$

Obtain the value of  $V_t$  by averaging the  
velocities at all the traverse points.

b. Stack gas volumetric flow rate, cfm:

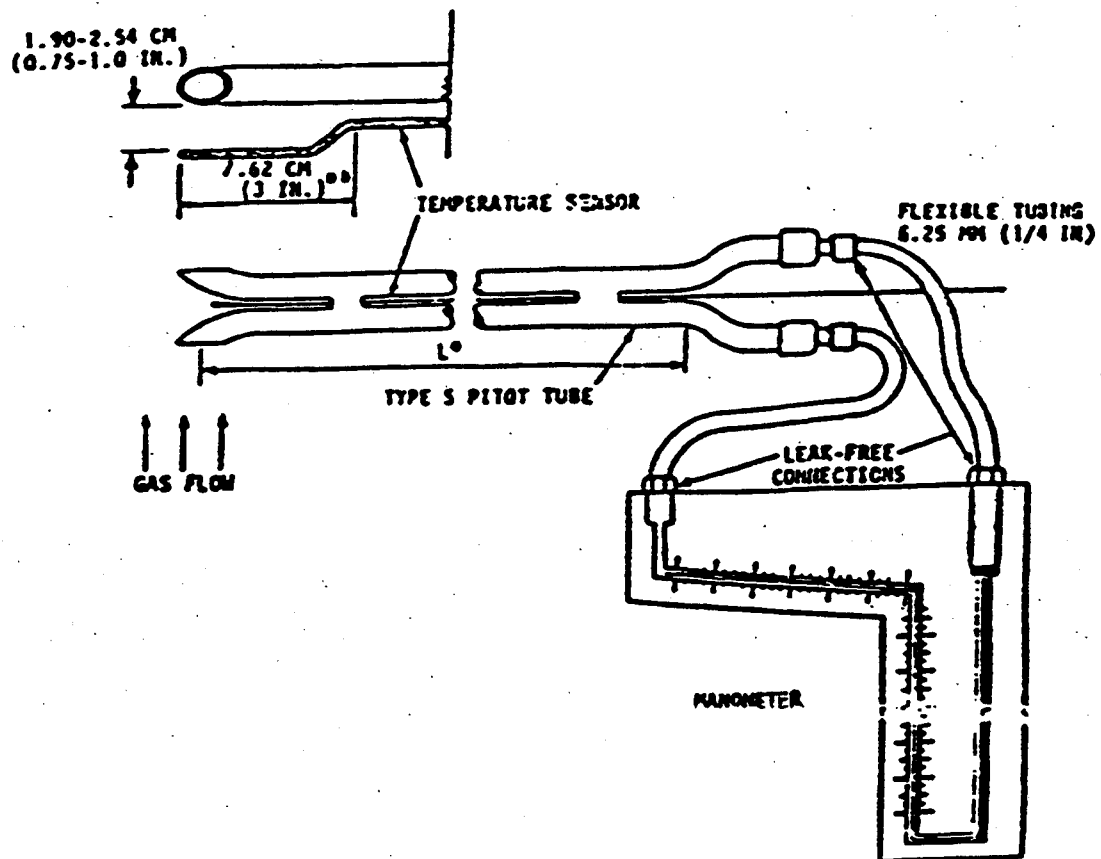
$$Q = C_p \cdot V_t \cdot F_d \cdot F_p \cdot A \cdot 60$$



c. Dry standard stack gas volumetric flow rate,  
scfm:

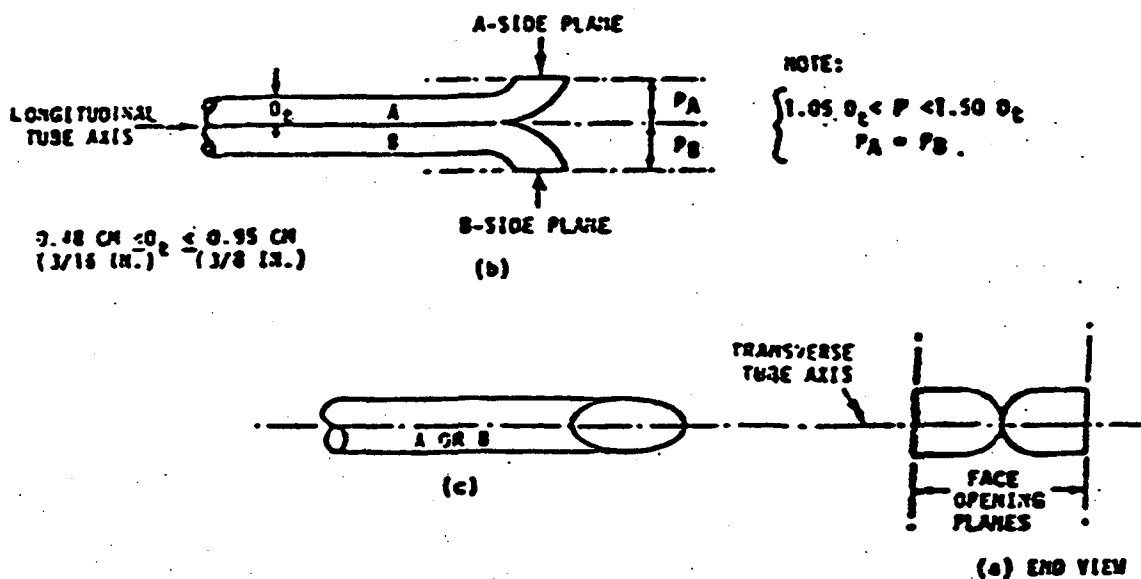
$$Q_{sd} = \frac{Q (P_s) (T_{std}) (100 - B_w)}{(P_{std}) (T_s + 460) (100)}$$

$$Q_{sd} = \frac{Q (P_s) (520) (1 - 0.01 B_w)}{29.92 (T_s + 460)}$$



\*L = Distance to Furthest Sampling Point Plus 30 CM (12 in.)  
 \*\*Pitot Tube - Temperature Sensor Spacing

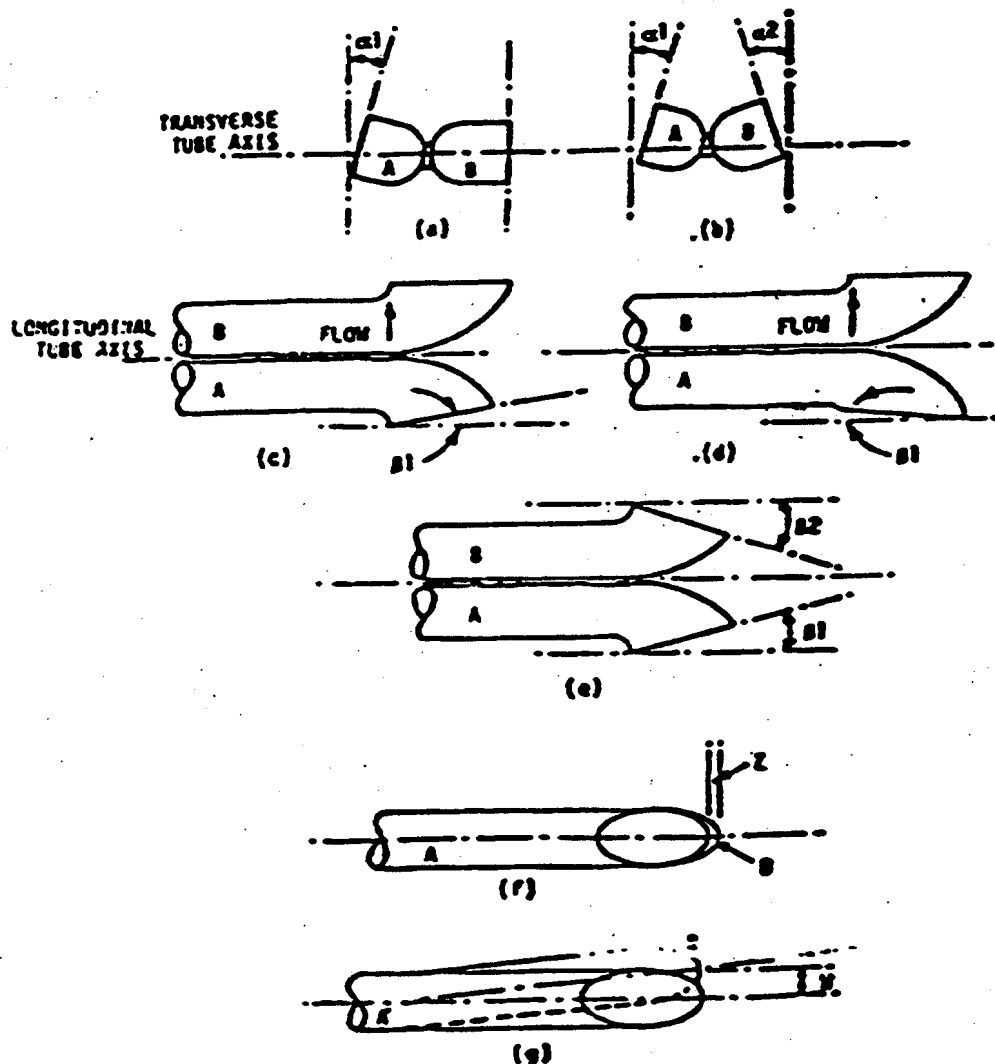
Figure 2.1-1  
 S-Type Pitot Tube-Manometer Assembly



Properly constructed S-type Pitot tube, shown in:

- End view; face opening planes perpendicular to traverse axis
- Top view; face opening planes parallel to longitudinal axis
- Side view; both legs of equal length and centerlines coincident, when viewed from both sides. Baseline coefficient values of 0.84 may be assigned to Pitot tubes constructed this way.

Figure 2.1-2  
S-Type Pitot Tube Dimension Specification



Types of face-opening misalignment that can result from field use or construction of S-type Pitot tubes. These will not affect  $C_p$  so long as  $\alpha_1$  and  $\alpha_2 \leq 10^\circ$ ,  $B_2 \leq 5^\circ$ ,  $z \leq 0.32$  cm (1/8 in.) and  $w \leq 0.03$  cm (1/32 in.)

Figure 2.1-3  
S-Type Pitot Tube Alignment Specification

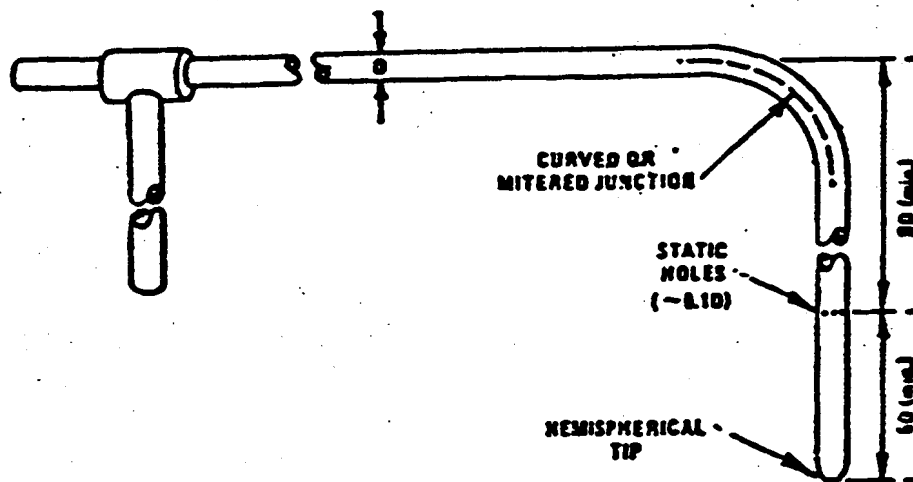


Figure 2.1-4  
Standard Pitot Tube Design Specifications

Test No. \_\_\_\_\_ Date \_\_\_\_\_  
Sampling Location \_\_\_\_\_

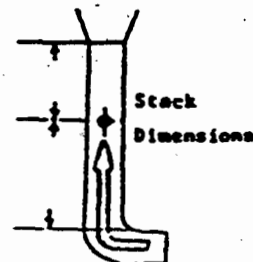
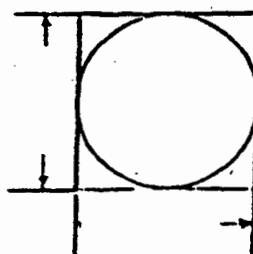
### Pre-Test Velocity Leak Check

### Post-Test Velocity Leak Check

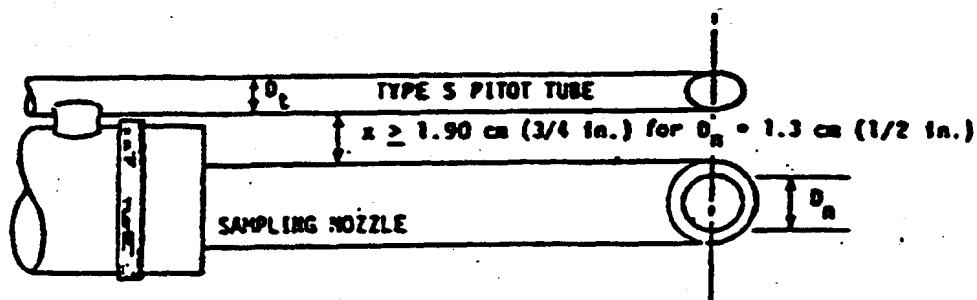
[illegible]

Static Pressure in Stack \_\_\_\_\_ "H<sub>2</sub>A (+/- \_\_\_\_\_ "H<sub>2</sub>O) (Average) \_\_\_\_\_  
 "H<sub>2</sub>A \_\_\_\_\_ "H<sub>2</sub>O \_\_\_\_\_  
 Recorded By \_\_\_\_\_

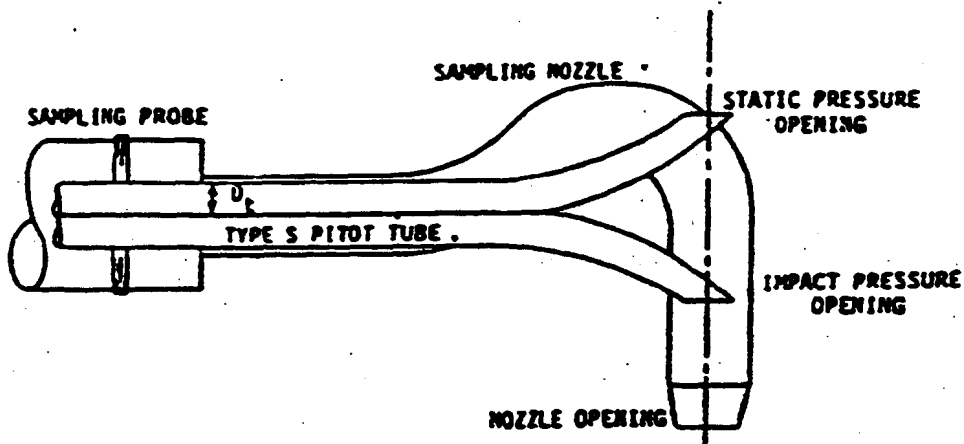
Magnetohelic No. \_\_\_\_\_ (Cal: \_\_\_\_\_)  
Pitot Tube No. \_\_\_\_\_ (Cal: \_\_\_\_\_)  
Potentiometer No. \_\_\_\_\_ (Cal: \_\_\_\_\_)  
Thermocouple No. \_\_\_\_\_ (Cal: \_\_\_\_\_)



2.1-27



(a) BOTTOM VIEW: SHOWING MINIMUM PITOT-NOZZLE SEPARATION.



(b) SIDE VIEW: TO PREVENT PITOT TUBE FROM INTERFERING WITH GAS FLOW STREAMLINES APPROACHING THE NOZZLE, THE IMPACT PRESSURE OPENING PLANE OF THE PITOT TUBE SHALL BE EVEN WITH OR DOWNSTREAM FROM THE NOZZLE ENTRY PLANE

Require Pitot tube-sampling nozzle configuration to prevent aerodynamic interference; buttonhook-type nozzle; centers of nozzle and Pitot opening aligned; in respect to flow direction,  $D_t$  between 0.48 and 0.95 cm (3/16 and 3/8 in.)

Figure 2.1-6  
Pitot Tube-Probe Assembly Specification

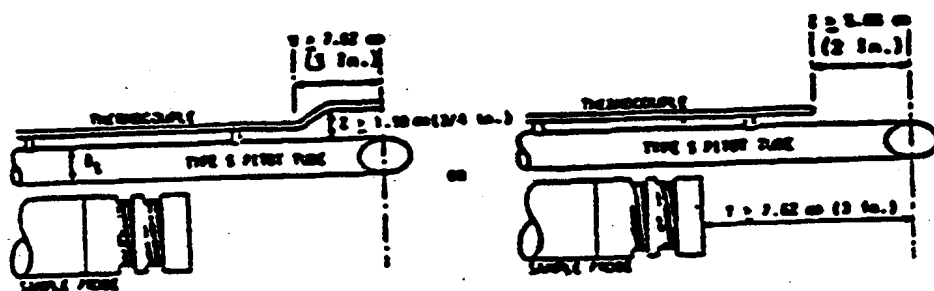


Figure 2.1-7

Proper Thermocouple Placement to Prevent Interference;  
 $D_t$  between 0.48 and 0.95 cm (3/16 and 3/8 in.)



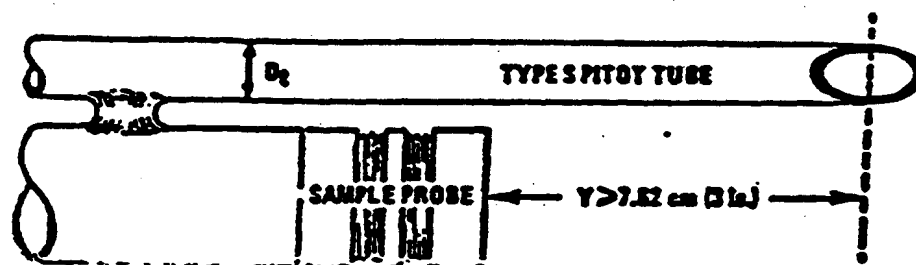


Figure 2.1-8

Minimum Pitot-Sample Probe Separation Needed to Prevent  
Interference:  $D_t$  Between 0.48 and 0.95 cm (3/16 and 3/8 in.)

# SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

Test No. \_\_\_\_\_ Sampling Train \_\_\_\_\_ Date \_\_\_\_\_  
 Calculated By \_\_\_\_\_ Checked By \_\_\_\_\_

## SOURCE TEST CALCULATIONS

### SUMMARY

A. Average Traverse Velocity (Pre-Test) .....                       fps  
 B. Average Reference Point Velocity (Pre-Test) .....                       fps  
 C. Average Traverse Velocity (During Test) .....                       fps  
 D. Gas Meter Temperature (Use 60°F, for Temp. Comp. Meters) .....            °F  
 E. Gas Meter Correction Factor .....                      

F. Average Stack Temp. ...            °F      L. Sampling Time .....            min  
 G. Stack Cross-Sect. Area .....            ft<sup>2</sup>      M. Nozzle Cross-Sect. Area .....            ft<sup>2</sup>  
 H. Barometric Pressure ...            "HgA      N. Net Sample Collection ..            mg  
 I. Gas Meter Pressure ....            "HgA      O. Net Solid Collection ..            mg  
 J. Total Stack Pressure ..            "HgA      P. Water Vapor Condensed ..            gal  
 K. Pitot Correction Factor .....                            Q. Gas Volume Metered ....            dscf

R. Corrected Gas Volume Metered  $\left[ (Q \times 1/29.92) \times \frac{520}{(460 + D)} \times E \right]$  .....            dscf

### PERCENT MOISTURE / GAS DENSITY

S. Percent Water Vapor in Gas Sample  $\left[ \frac{4.64 \times P}{(0.0464 \times P) + R} \right]$  .....            %

T. Average Molecular Weight (Wet):

(Component)	(Volume % / 100) x (1 - S/100) x (Molec. Wt.) = (Wt./Mole)		
Water		1.00	18.0
Carbon Dioxide	Dry Basis		44.0
Carbon Monoxide	Dry Basis		28.0
Oxygen	Dry Basis		32.0
Nitrogen/Inerts	Dry Basis		28.2
(Sum)			

### FLOW RATE

U. Gas Density Correction Factor ( $\sqrt{28.95/T}$ ) .....             
 V. Flue Correction Factor (A/B) .....             
 W. Velocity Pressure Correction Factor ( $\sqrt{29.92/J}$ ) ...             
 X. Corrected Velocity (C x K x U x V x W) .....            fps  
 Y. Flow Rate (X x G x 60) .....            cfm  
 Z. Flow Rate  $\left[ Y \times \frac{J}{29.92} \times \frac{520}{(460 + F)} \right]$  .....            scfm  
 AA. Flow Rate  $\left[ Z \times (1 - S/100) \right]$  .....            dscfm

### SAMPLE CONCENTRATION/EMISSION RATE

BB. Sample Concentration (0.01543 x N/R) .....            gr/dscf  
 CC. Sample Concentration (54,143 x BB/            Molec. Wt.) ...            ppm (dry)  
 DD. Sample Emission Rate (0.00857 x AA x BB) .....            lb/hr  
 EE. Solid Emission Rate ( $\frac{0.0001322 \times O. \times AA}{R}$ ) .....            lb/hr  
 FF. Isokinetic Sampling Rate ( $\frac{S \times R \times V \times 100}{L \times M \times AA}$ ) .....            %

Figure 2.1-9

Calculation Sheet